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Review of technology in small-scale biomass combustion systems in the European market

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ABSTRACT

This work studied the importance of wood pellets, chips and wood logs for small- and medium-scale heat production. Pellet use can contribute substantially to reaching the renewable heat and electricity goals set by the European Union (EU) Renewable Energy Directive. Consequently, to integrate into European energy markets, pellet use must be a key piece of the EU energy policy.

This study provides a wide perspective on the state-of-the-art small-scale biomass combustion units, particularly those that use pellets for fuel. Small-scale combustion units include stoves and boilers with capacities less than 200 kW. A wide market review has been conducted, including a review of the literature and information from manufacturers and test institutes. A database has been created, which includes 186 companies and offers 995 different models, providing an extensive view of the European market. The large number of new companies shows that the solid-fuel boiler market is continuously increasing across Europe. The technologies that are currently the most widely used are described and compared.

Contents

1. Introduction

According to the European Renewable Energy Observatory (EurObserv'ER) [1], "primary energy output from solid biomass combustion rose in 2009 yet again to a new height of 72.8 Mtoe, which equates to a 3.6% increase on 2008". Another source [2] suggests a production of more than 8 million tons of solid biomass.

The European biomass heat industry is highly diversified because it covers residential service and the institutional and industrial markets. The boiler manufacturers, therefore, offer very wide ranges of capacities, from a few kilowatts to a few megawatts. This paper discusses the small- and medium–small-range capacities, which includes capacities up to 200 thermal kW.

The importance of wood pellets for small- and medium-scale heat production is continuously increasing across Europe. In the last few years, the sector's growth has been assisted by several incentives from public authorities, especially in central and northern Europe. These incentives have enabled biomass boiler technology

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to progress extraordinarily in the last decade, achieving high efficiency and reliability while lowering solid and gaseous pollutant emissions. However, a wide quality range still exists in the boiler market, which means that a boiler must be chosen carefully based on its intended use [3–5].

Compared to conventional heating systems, such as oil or gas boilers, biomass heating technology has some disadvantages in terms of required space, efficiency, emissions and maintenance [6–12].

Many combustion technologies are available for biomass combustion, such as fixed bed combustion, fluidised bed combustion and pulverised bed combustion [13].

1.1. When are they cost-effective?

Every biomass is different, both chemically and physically, so boilers must be designed specifically for a particular biomass. Small-scale boilers are designed for fuels with certain characteristics that are regulated by either common practice or a quality classification memorandum. Examples of fuels for small-scale boilers include pellets and chips. Large-scale boilers are designed for the use of a particular fuel, and only small deviations in the fuel's characteristics are accounted for.

To take full advantage of the given fuel, the quality of the biomass used in the heating system must fulfil the boiler's fuel requirements. The most important fuel characteristics are granulometry, density, heating power, humidity, ash content, chlorine content and fusibility ash temperature.

Demirbas [14,15] reviews several topics that are associated with burning biomass in boilers, including the composition of biomass, estimating the higher heating value of biomass, the contrast between biomass and other fuels, the combustion of biomass, co-firing of biomass and coal, the impacts of biomass, the economic and social aspects of biomass, the transportation of biomass, densification of biomass and the future of biomass in the energy contest.

The investment required for a biomass boiler is larger than for fossil fuel boilers, but the fuel cost is clearly lower. There are remarkable differences in quality (density, heating value, humidity and ash content) among the different biomasses. Of course, quality depends on qualities such as the region of origin and the production year. However, even with fluctuations in quality, the cost of biomass fuel remains lower than the cost of fossil fuels, making biomass a competitive alternative to fossil fuel.

The application of biomass offers many economic advantages, such as the following: conservation of fossil fuel resources, reduction of the dependence on fuel imports, utilisation of agricultural and forest residues, reduction of emission of harmful species from fossil fuel combustion, re-cultivation of non-utilised farming areas and minimisation of waste disposal [16–18].

2. Methodology

The research presented here has been conducted by studying information from test institutes, international journals, conference proceedings, national pellet associations, company web pages, books, manufacturers' instructions and the internet. The starting point has been the work titled "Förderbare automatisch beschickte Biomasseanlagen" (2008) from the Austrian Bioenergy Centre GmbH [19]. A database was created that includes all 27 EU countries and Norway and Switzerland. The inventory is intended to be exhaustive.

The database includes the following information:

1. Country
2. Type (boiler or stove)

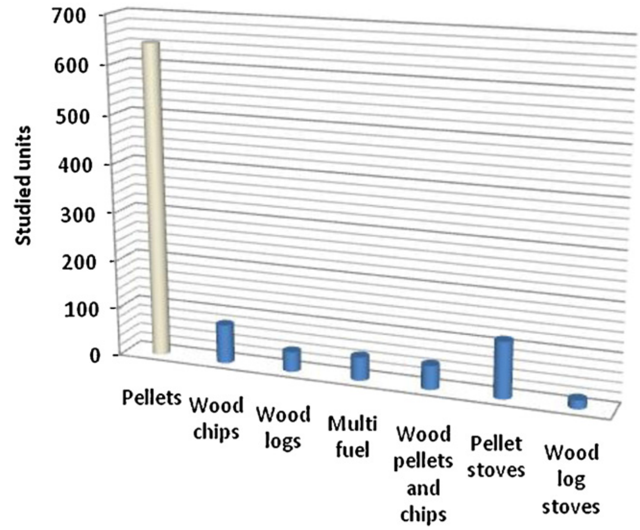

Fig. 1. Number and type of studied units in the data matrix.

3. Efficiency (%)
4. Type of fuel
5. Power range (kW)
6. Type of feeding
7. Type of burner design
8. Ignition system
9. Type of control and regulation system
10. Heat exchanger
11. Cleaning system of the heat exchanger
12. Ash cleaning system
13. Nominal CO emissions (mg/m^3)
14. Nominal particle emissions (mg/m^3)
15. CO emissions at partial charge (mg/m^3)

The research involved designing a data matrix that couples devices with fuels. Two types of devices, boilers and stoves, can be found on the market, and five types of fuels are available: wood pellets, wood logs, chips, chips mixed with pellets and multi-fuels (such as pellets, chips and almond shells).

This matrix couples boilers and stoves with fuels. There are many possible combinations, but this paper will only focus on the six most common combinations found on the market. Five of these combinations use boilers, and one uses a stove.

Fig. 1 presents the devices used for each fuel. These combinations are as follows: boiler with wood pellets, boiler with wood chips, boiler with wood logs, boiler with chips and pellets (pellet-and-chip boiler), multi-fire or multi-fuel boilers and, finally, pellet stoves.

The distribution of manufacturers by country is shown in Fig. 2. The manufacturing companies included in Fig. 2 offer a wide range of boilers. In the studied market, the most relevant countries are Germany (5% of market), Austria (22% of market) and Italy. Germany has many original equipment manufacturers (OEMs) located in other countries. In other countries, there are few manufacturers, but there is high pellet production. For example, in Spain, there are few boiler companies, but pellet production has increased tenfold in the last 3 years. Most of that product is sold abroad because the internal demand is still low. Other fuels that have less market penetration, such as olive stone or olive residue ("orujillo" in Spanish), are also exported in large quantities.

With 80% of the products offered, Austria and Germany have the widest variety of products and portfolio classifications.

Pellet boilers compose 31% of the market, log boilers compose 22% of the market, and chip boilers compose 17% of the market. The

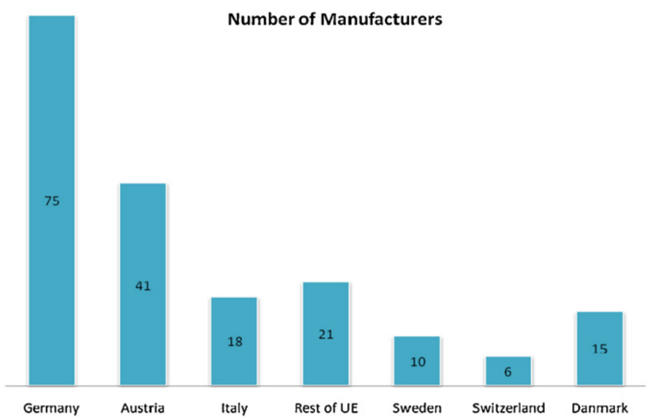

Fig. 2. Number of manufacturers per distributing country.

rest of the market is composed of pellet boilers used in combination with other fuels, primarily chips (Fig. 3).

3. Results

3.1. Main parts and technological options

The main parts are generally speaking:

- Combustion chamber/burner/ignition systems
- Feeding system
- Heat exchanger

These three parts are part of the boiler, no matter if the fuel is fed with solid, liquid or gaseous fuels.

Heat exchanger is mainly a piro-tubular type. In pellet boilers this type of heat exchanger reaches 90.3% of the market. Acua-tubular type of heat exchanger is only relatively important in chips boilers (36%), log boilers (26%) and in pellet and chips boilers (27%). The type of heat exchanger gathers also with the position: 80% are placed vertically. Only in multi fuel boilers (>60%) and pellet stoves (40%) other positions are preferred to place the heat exchanger.

3.1.1. Types defined according to the burner

A burner is a well-designed unit used to continuously burn a certain type of fuel. Some burners are equipped with a small manually or automatically fed box or silo, which is used to store the fuel and feeds from a larger silo (Fig. 4).

The three main kinds of burners are fixed bed, moving grate and burning plate (volcano type). Almost all pellet boilers (99.3%) and wood-log boilers use fixed bed burners.

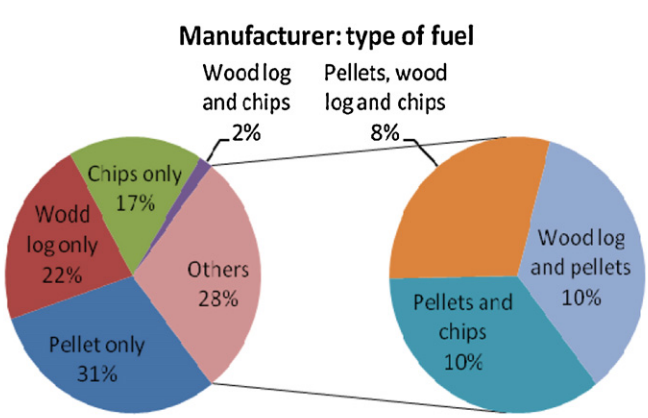

Fig. 3. Market distribution according to fuel type.

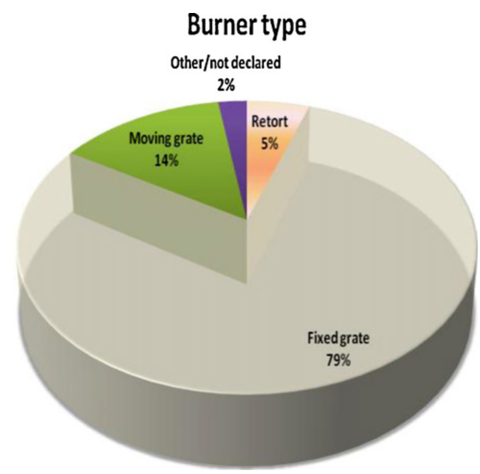

Fig. 4. Usage of burner types.

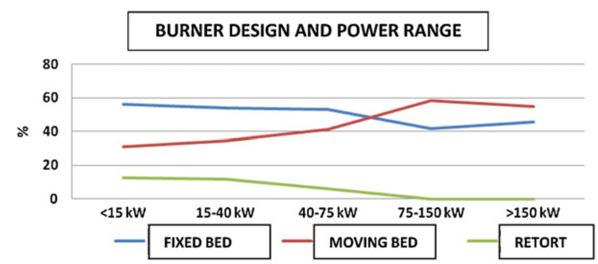

Fig. 5. Type of burner technology related to fuel used.

The data reveal that the moving grate design is preferred in 41.3% of chip boilers and 22.9% of pellet-and-chip boilers.

The burning plate design (5% of all boilers) involves constant fuel addition. The fuel is forced through a pipe and fed into the burning bed from below the plate. The new fuel pushes the partially combusted particles outward until the completely burned particles from the outer circle fall from the retort.

The data matrix shows that as the power of the unit increases, the moving grate becomes increasingly preferable, especially for boilers with capacities greater than 40 kW. In addition, the power gains of the burning plate design diminished and almost disappeared for capacities greater than 100 kW (Figs. 5 and 6).

A deeper study of the fixed-grate type of burner shows that there are different arrangements: fixed grate with horizontal feeding, which is the most common; ring burners with air injectors steel cylinders with cement or stainless steel cylinders and funnel grates (Fig. 7).

The stainless steel in fixed grates is the most common material used by manufacturers due to its low cost. However, this material resists low heat for long periods of time. To avoid this disadvantage, some producers use refractory steel that greatly improves the early stages of combustion by rapidly becoming incandescent and

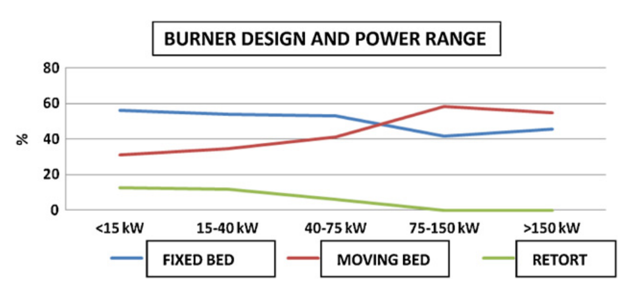

Fig. 6. Type of burner according to nominal power of the boiler.

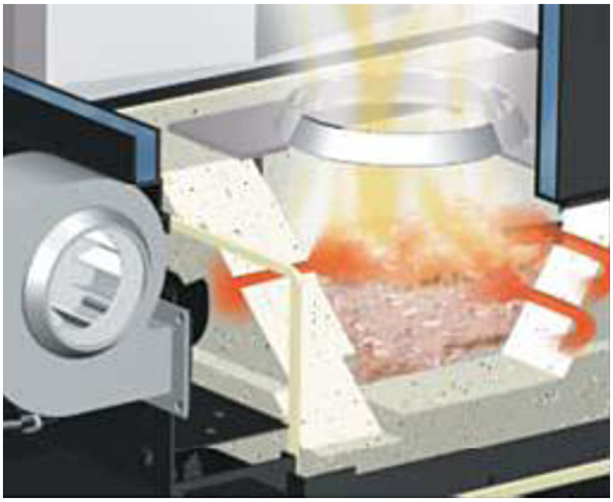

Fig. 7. Combustion chamber of a refractory brick burner.

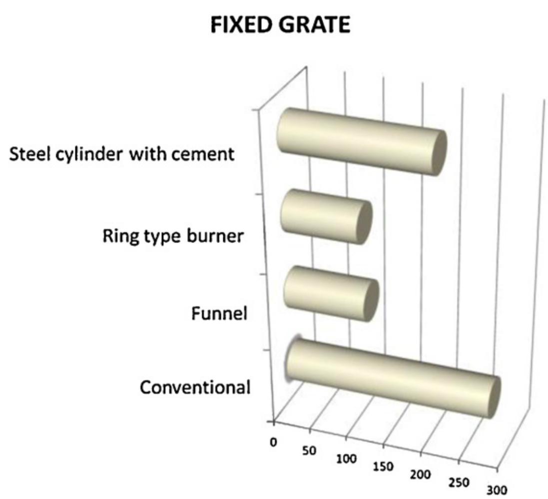

Fig. 8. Distribution of types of fixed grates.

eliminating the unburned gases. A second option is using refractory bricks (firebricks), which are more resistant to heat stocking (Figs. 8 and 9).

The wood chip boilers primarily use ring burners (21%), while pellet boilers are primarily made with steel cylinders and cement (35%). In wood log boilers, multi-fuel boilers and pellet stoves, the fixed grate with a horizontal feeding design is the most widely used (80%) (Fig. 10).

Funnel fixed grate: This type of plate allows the largest amount of cinder on the smallest surface, which reduces energy loss (Fig. 11).

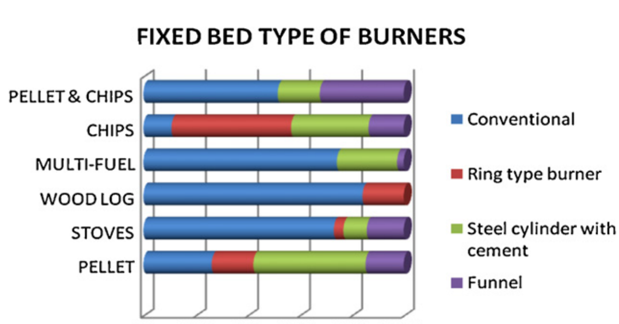

Fig. 9. Most-used fuels with fixed grates.

Fig. 10. Example of a ring burner with air injectors.

Moving grates: Wood log boilers and small pellet stoves or boilers rarely use these types of burners. They are also uncommon in other burning technologies, making up only 14% of the market. However, there is a very interesting design among these grates: the *bascule grate*. This design allows the removal of cinder to the ash box below the grate, which prevents the accumulation of cinders on the grate surface and maintains an almost constant boiler performance. This type of burner is used in 33% of chip boilers and pellet-and-chip boilers. The grate can turn more than 90 degrees at regular intervals. Another variation is the *hinged grate*, which is a type of vibratory grate that is used with fuels that are prone to agglomerating. With the hinged grate, the feeding process is permanent and regular with a roughly uniform distribution of the fuel due to the movement of the grate. This system is used predominantly in pellet-and-chip boilers (Figs. 12 and 13).

In pellet and multi-fuel boilers, step-grates are very common. The fuel receives the primary air from beneath the grate, which allows both good refrigeration of the grate and pre-heating of the combustion air. This design ensures near-constant performance (Figs. 14 and 15).

Two types of grates can be considered sub-types of the moving grate. The rotator grate enables the automatic and intermittent dis-

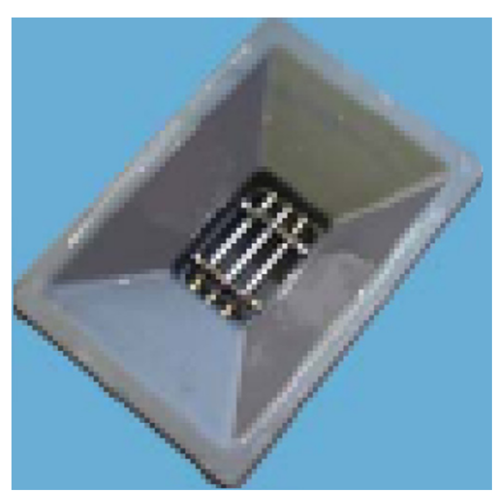

Fig. 11. Funnel fixed grate type of burner.

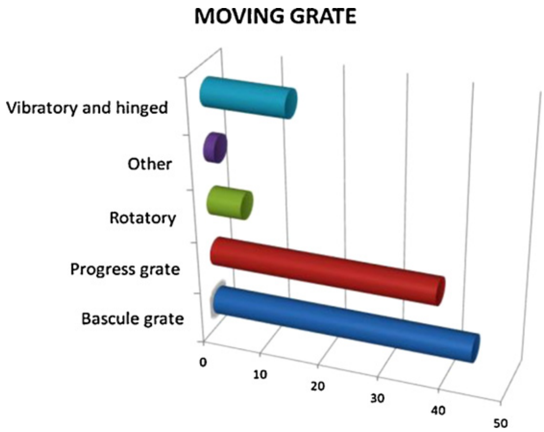

Fig. 12. Main types of moving grates.

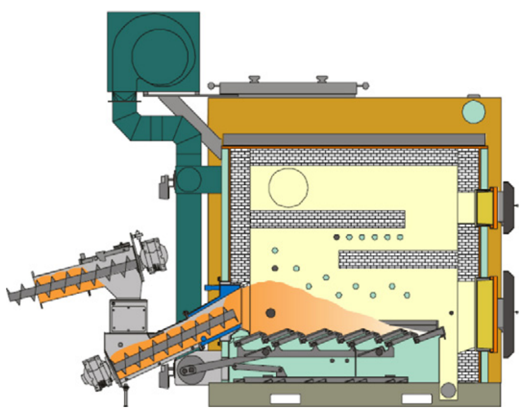

Fig. 13. Distribution of fuel types with moving grates.

charge of ash and is most commonly used in multi-fuel burners but seldom used in pellet boilers. With a rotating cylinder grate, the grate movement ensures that the combustion area is continuously agitated, thereby allowing complete combustion with minimum ash production (Fig. 16).

3.1.2. Types of ignition systems

The fuel ignition is performed automatically in 94% of the boilers studied using one of the following techniques:

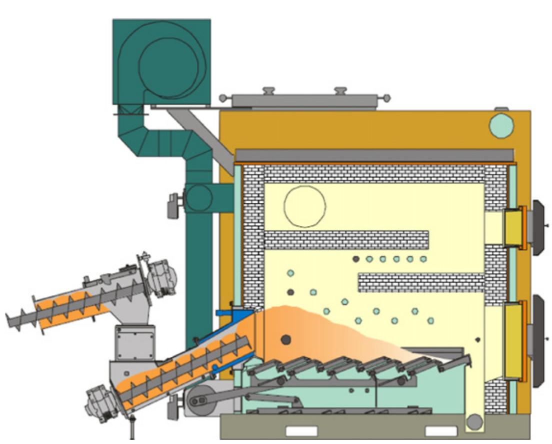

Fig. 14. Example of a progress moving grate.

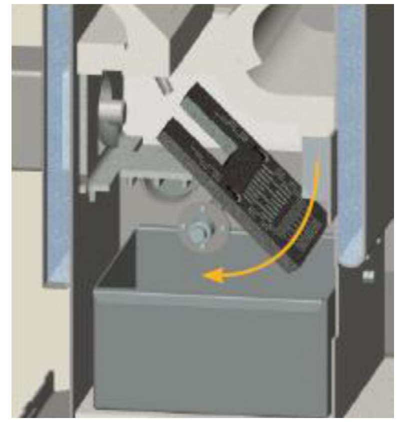

Fig. 15. Example of a tilt moving grate.

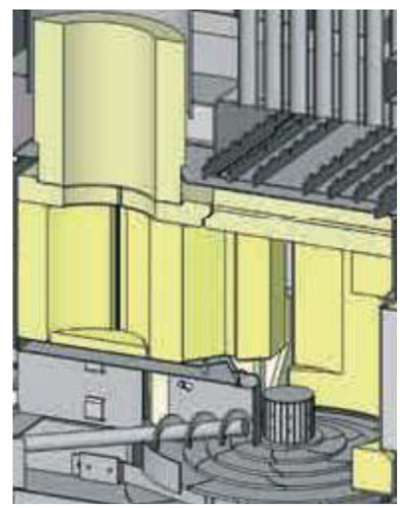

Fig. 16. Example of a rotator moving grate.

- *Using hot air* (35%): A hot-air generator produces the ignition flame, which is controlled by a micro-processor located in the equipment's electronic board.
- *Using electricity* (53%): Electric ignition is used in half of the boilers studied and is produced using an electric resistance.
- *Using ceramic ignition*: Ceramic ignition may also be used, which comprises a ceramic incandescent rod. This ignitor consumes only 250 W of electricity, giving it an advantage over hot-air ignition, which consumes 1500–1800 W (Figs. 17 and 18).

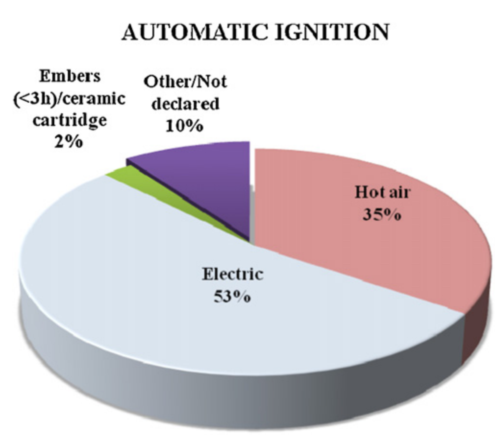

Fig. 17. Different types of ignition systems.

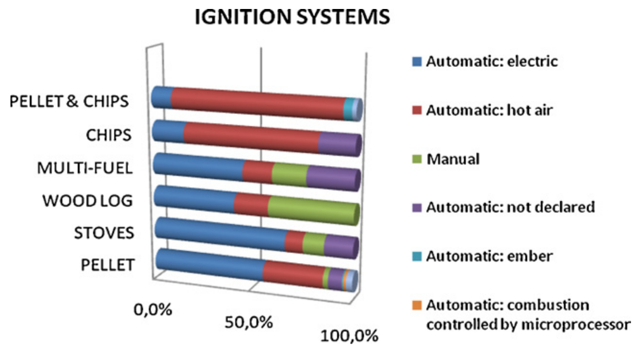

Fig. 18. Different types of ignition systems according to type fuel.

In 56% of pellet boilers and 66.9% of pellet stoves, ceramic ignition is the preferred type of ignition system, while in 66.3% of chip boilers and 83.7% of pellet-and-chip boilers, the preferred ignition system is automatically supplied hot air. Wood log boilers still use a manual plug ignition.

3.1.3. Types of feeding systems

The majority of the wood log burners are hand-fed horizontally. The rest of the burners are classified as one of three different types according to their feeding systems: bottom-fed burners, horizontally fed burners, and top-fed burners.

Bottom-fed burners (*underfeed stoker or underfeed retort burners*): The fuel in this type of burner is fed into the bottom of the combustion chamber or combustion retort grate. The most commonly used fuels are wood chips (approximately 40%), wood pellets (20%) and pellets and chips. The system employed for the feeding is generally a screw auger that transports the fuel to the combustion zone. Additionally, part of the primary air is supplied with the fuel supply (Fig. 19).

Horizontally fed burners: This feeding system is the most commonly used system for wood chip and multi-fuel burners and is sometimes used on wood pellet burners (Figs. 20 and 21).

Top-fed burners: This type of feeding system was developed for pellet combustion and is used in 55% of pellet boilers and over 70% of pellet stoves. Pellets are fed from the top and dropped down to the bed. The main advantage is the division between the feeding system and the flame is that it allows better control of the amount of fuel fed. The disadvantage is that the falling pellets produce poor combustion on the bed, increasing the amount of unburned products and dust (Fig. 22).

Feeding from above is the main system in low-power (<15 kW) boilers. As the power increases over 40 kW, the preferred systems are substituted by a horizontal-type feeding system. Feeding the bed from below is common for all power ranges in an almost constant proportion (20–30%) (Fig. 23).

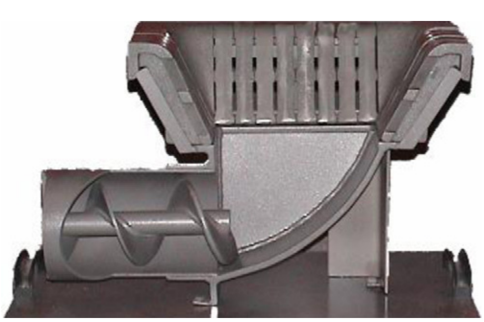

Fig. 19. Bottom-fed burner.

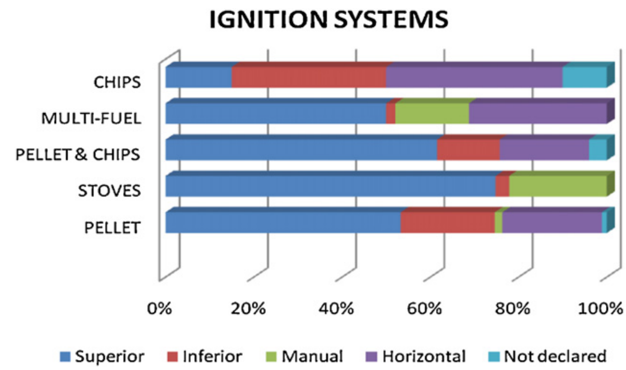

Fig. 20. Different types of feeding systems classified by fuel type.

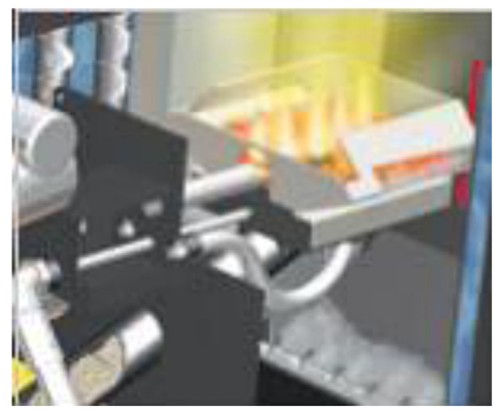

Fig. 21. Example of fixed bed with horizontal feeding.

3.2. Control techniques

The most highly developed boilers on the market have an automatic control system, with various control parameters that are applied depending on the manufacturer. This control is very important for guaranteeing the best possible performance and the lowest possible emissions in every situation. This performance must be obtained at both nominal (total) and partial power, at both the start and end of combustion and when the demand charge changes.

The most common control device for combustion is the lambda probe. This probe is placed in the chimney and detects and controls the oxygen concentration. The goal is to adjust the oxygen levels to ensure complete combustion. The secondary air supply is increased or decreased until the minimised oxygen level is achieved. The lambda probe control is used in 78.5% of chip boilers and 85.7% of pellet-and-chip boilers. Surprisingly, only 39% of the wood-log-manufactured boilers utilise lambda control, while 61% report having no control at all.

Modular control techniques are implemented in more than 40% of pellet boilers and stoves (Fig. 24).

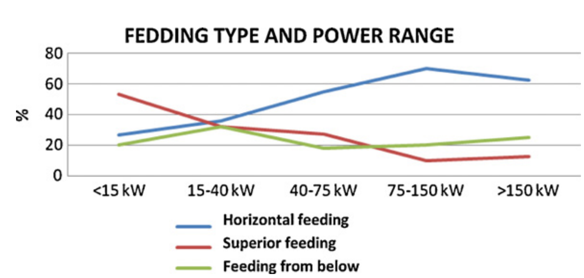

Fig. 22. Type of feeding depending on the power.

Fig. 23. Example of a fixed bed in which the fuel is fed from the top of the bed.

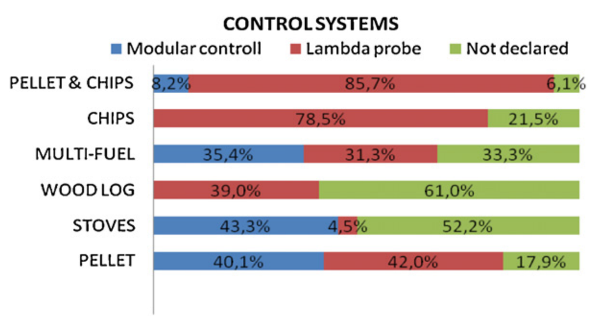

Fig. 24. Type of control systems according to fuel type.

The use of the lambda probe becomes more common as the power of the boiler increases and is slightly less common with other modulation systems.

Austrian and German pellet boilers with lambda controllers are already state-of-the-art [20–22], whereas Swedish pellet heating devices often use only manual adjustment [23–25] (Figs. 25 and 26).

Most manufacturers provide the option of a control panel so that the consumer has the capability to regulate variables such as air demanded in combustion, velocity of the air funs, fuel charge, management of the fuel storage tank, water tank regulation, and water temperature (Fig. 27).

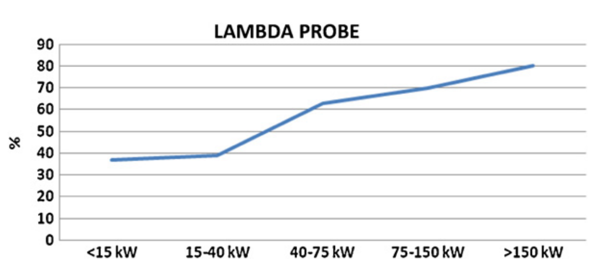

Fig. 25. Use of the lambda probe as a function of boiler power.

Fig. 26. Lambda probe.

3.3. *Unburned particles and ash management*

3.3.1. *Ash removal from combustion bed*

Modern biomass boilers produce a very low volume of ash due to very clean and efficient combustion. Both the ash deposited in the burner and the fly ash from the combustion chamber must be considered. These ashes are collected in store boxes that are inserted in the boiler specifically for that purpose. The ash collected in the burner is eliminated automatically. These burners are often constructed with specific mechanisms to eliminate this ash, such as vibratory grates, shakers, vibrators, hinge device, swing grate, and so on. In other boilers the user has to remove every week or every 2 weeks the deposited ahs residues although manufacturers of these systems claim that the ash needs to be removed only once to three times per year [26–30].

67% of all boilers are constructed with automatic ash removal systems. Of them the most common (56%) is the helicoidally screw auger.

The analysis of these systems according to the type of fuel reveals that pellet stoves and wood log boilers do not have automatic systems, and ash has to be removed manually. For the rest of fuels the most frequent employed system is the screw auger: 88.8% in the case of chip boilers, decreasing to 39.8% in pellet boilers, and 33.3% of pellet-and-chip boilers (Figs. 28 and 29).

3.3.2. *Cleaning of the water heat exchange tubes*

In 78% of the boilers, the heat exchange tubes are cleaned automatically using two types of completely different technologies:

A. *Mechanical system*: The heat exchange is provided by devices located in the flue gas passage to remove ash and slag. Examples of this type of system include cleaning by springs; turbulating blades that also serve as turbulators that improve the heat transfer by creating a turbulent air flow; levers; vibrating devices and helicoidal screw augers.
B. *Flow recirculation systems*: These systems are high-speed air recirculation systems. A portion of the combustion gases are

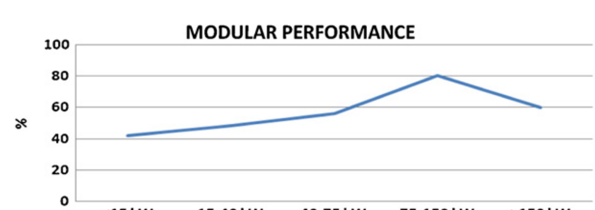

Fig. 27. Modular performance as a function of boiler power.

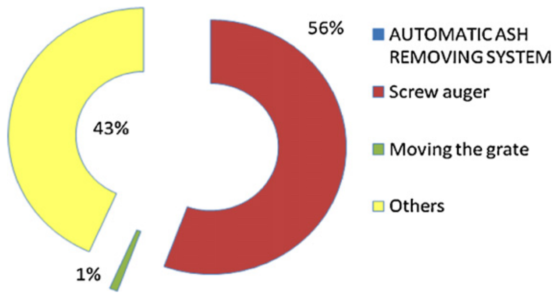

Fig. 28. Automatic ash removal systems.

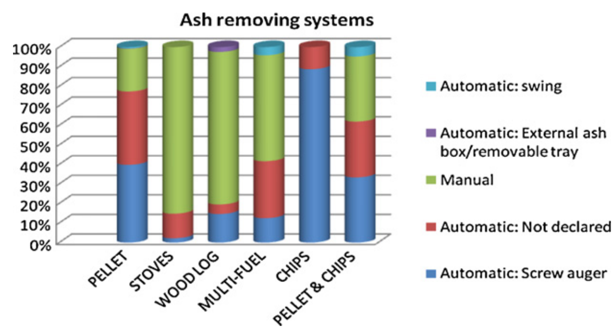

Fig. 29. Usage of automatic ash removal systems by fuel type.

forced through the heat exchanger at high speed and drag in the deposited particles, which are later eliminated in a cyclone.

However, the cleaning of the heat exchanger tubes in certain boilers is fulfilled semi-automatically, such as turbulence generators that must be activated manually by a lever placed outside of the boiler.

Boilers with horizontal passages, often used for oil boilers, are not suitable for pellet boilers because flue-ash and slag deposit much more easily, requiring shorter maintenance intervals (Figs. 30 and 31).

Sixty-three percent of the studied cleaning systems use turbulators, 22% use coils, and 9% use flow recirculation (Fig. 32).

4. Summary

This research compares the different technologies used in biomass combustion systems.

Once the data matrix was created, six different combinations of fuels and boilers were chosen for the study: wood pellet stoves, pellet boilers, pellet-and-chip boilers, chip boilers, wood log boilers and multi-fuel boilers. The present state-of-the-art technology of these boilers is highly variable and depends on the types of fuel and the combination used.

Nearly all pellet stoves (99.3%) and wood log boilers (93%) use a fixed grate.

The moving grate is used in 41.3% of chip boilers and 22.9% of pellet and chip boilers. As the power of the boiler increases, the use of moving grates becomes more frequent, especially for powers over 40 kW. However, retort-type grates are used less frequently for boiler powers of over 100 kW. Wood log boilers and small pellet stoves do not use moving grates. In addition, the moving grate is only used in 14% of the other technologies. Of this 14%, the bascule type stands out because it allows the transportation of ash and cinders to the ash box holder below the grate. In pellet boilers, and especially multi-fuel boilers, the step grate is used.

In 56% of pellet boilers and 66.9% of pellet stoves, an automatic electric ignition system is used, whereas in 66.3% boilers that burn chips and 83.7% of systems that burn pellets and chips, the hot-air automatic system is used.

In bottom-fed burner systems (underfeed stoker or underfeed retort burners), the fuel is fed into the bottom of the combustion chamber or the combustion retort. The most commonly used fuels are wood chips (nearly 40%), wood pellets (20%), and pellets and chips. The screw conveyor is used as the feeder system.

Feeding from above (gravitational) is common in low power boilers (<15 kW), 55% of pellet boilers, and over 70% of pellet stoves. Gravitational feeding is replaced by horizontal feeding in boilers with a power greater than 40 kW. Feeding from below is used irrespective of power.

The most developed boilers in the market have an automatic control system with different control parameters. The type of control parameter depends on the manufacturer. The lambda probe

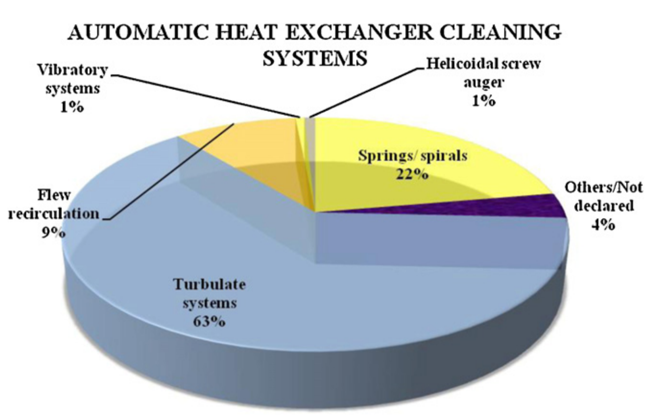

Fig. 30. Distribution of types of cleaning systems of heat exchanger tubers.

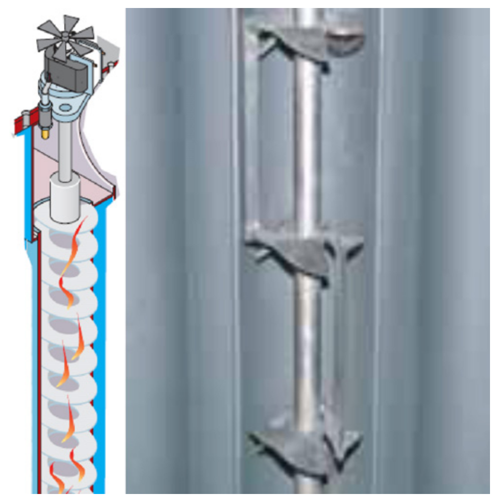

Fig. 31. Turbulence generators.

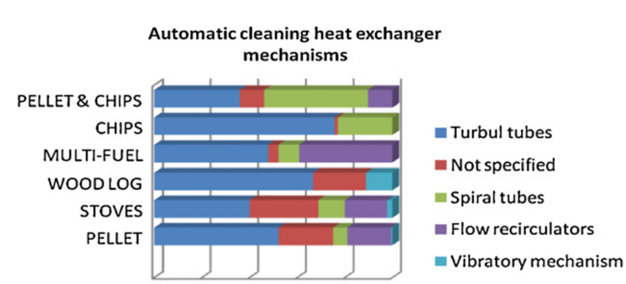

Fig. 32. Types of heat exchanger cleaning systems used by fuel types.

is preferred in 75.5% of chip boilers and 85.7% of pellet-and-chip boilers. Modern biomass boilers generate a very small volume of ash due to clean and efficient combustion. Sixty-seven percent of boilers have some type of automatic ash disposal system. The most common system is the auger, which is used in about 88.8% of chip boilers, 39.8% of pellet boilers and 33.3% of pellet-and-chip boilers.

Use of automatic heat exchanger cleaning systems has increased to 78% of boilers in recent years. The preferred cleaning device has been turbulators, which are used in 63% of the boilers studied. Springs or spirals are used in 22% of the boilers, and flow recirculation systems are used in only 9% of the boilers.

It is important to recognise that the development of biomass energy will be largely dependent on the development of the renewable energy industry as a whole because it is driven by similar energy as well as environmental, political, social and technological considerations.

References

[1] BAROMÈTRE BIOMASSE SOLIDE – EUROBSERV'ER – NOVEMBRE; 2010: 122–39.
[2] Pellet market overview report EUROPE. Pelletatlas, WIP Renewable Energies; December 2009.
[3] Mola-Yudego MSB, Röser D, Prinz R, Sikanen L. Present and future trends in pellet markets, raw materials, and supply logistics in Sweden and Finland. Renewable and Sustainable Energy Reviews 2010;14:3068–75.
[4] Peksa-Blanchard M, Dolzan P, Grassi A, Heinimö J, Junginger M, Ranta T, et al. Global wood pellets markets and industry: policy drivers. Market status and raw material potential. IEA Bioenergy Task 40; 2007.
[5] Höglund J. The Swedish fuel pellets industry: production, market and standardization. Swedish University of Agricultural Sciences, Examarbeten Nr 14; 2008: ISSN:1654-1367.
[6] Vermaa VK, Bramb S, De Ruycka J. Small scale biomass heating systems: standards, quality labelling and market driving factors—an EU outlook. Biomass and Bioenergy 2009;33:1393–402.
[7] Vinterback J. Pellet 2002: the first world conference on pellets. Biomass and Bioenergy 2004;27:513–20.
[8] Fiedler F. The state of the art of small-scale pellet-based heating systems and relevant regulations in Sweden, Austria and Germany. Renewable and Sustainable Energy Reviews 2004;8:201–21.
[9] Kjällstrand J, Olsson M. Chimney emissions from small-scale burning of pellets and fuel wood-examples referring to different combustion appliances. Biomass and Bioenergy 2004;27(6):557–61.
[10] Obernberger I, Thek G. Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. Biomass and Bioenergy 2004;27:653–69.
[11] Heschel W, Rweyemamu L, Scheibner T, Meyer B. Abatement of emissions in small-scale combustors through utilisation of blended pellet fuels. Fuel Processing Technology 1999;61(3):223–42.
[12] Olsson M, Kjällstrand J. Low emissions from wood burning in an ecolabelled residential boiler. Atmospheric Environment 2006;40(6):1148–58.
[13] Van Loo S, Koppejan J. The handbook of biomass combustion and co-firing. UK: Earth Scan; 2008.
[14] Saidur R, Abdelaziz EA, Demirbas A, Hossain MS, Mekhilef S. A review on biomass as a fuel for boilers. Renewable and Sustainable Energy Reviews 2011;15(June (5)):2262–89.
[15] Demirbas A. Potential applications of renewable energy sources, biomass combustion problems in boiler power systems and combustion related environmental issues. Progress in Energy and Combustion Science 2005;31: 171–92.
[16] Demirbas A. Social, economic, environmental and policy aspects of biofuels. Energy Education, Science and Technology B: Energy Science 2010;2(1–2):75–109.
[17] Spliethoff H, Hein KRG. Effect of co-combustion of biomass on emissions in pulverized fuel furnaces. Fuel Processing Technology 1998;54:189–205.
[18] Hein KRG, Bemtgen JM. EU clean coal technology co-combustion of coal and biomass. Fuel Processing Technology 1998;54:159–69.
[19] Austrian Bioenergy Centre GmbH. Förderbare automatisch beschickte Biomasseanlagen. Austrian Bioenergy Centre GmbH; 2008.
[20] Fröling Heizkessel- und Behälterbau Ges.m.b.H, http://www.froeling.at/.
[21] Kalkgruber Solar- und Umwelttechnik GmbH, http://www.solarfocus.at/.
[22] SHT-Heiztechnik GmbH, http://www.sht.at.
[23] Thermia Värme AB, http://www.thermia.se.
[24] Scand-Pellet AB, www.scand-pellet.se.
[25] Effecta-Pannan AB, http://www.effectapannan.se/.
[26] Van Loo S, Koppejan J. The handbook of biomass combustion and co-firing. UK: Earth scan; 2008.
[27] Hughes EE. Biomass co-firing: economics, policy and opportunities. Biomass and Bioenergy.
[28] Wiinikka H, Gebart R. Experimental investigations of the influence from different operating conditions on the particle emissions from a small-scale pellets combustor. Biomass and Bioenergy 2004;27(6):645–52.
[29] Messerer A, Schmatloch V, Pöschl U, Niessner R. Combined particle emission reduction and heat recovery from combustion exhaust—a novel approach for small wood-fired appliances. Biomass and Bioenergy 2007;31(7): 512–21.
[30] Johanssona LS, Lecknerb B, Gustavssona L, Cooperc D, Tullina C, Potterc A. Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. Atmospheric Environment 2004;38: 4183–95.